# Identification of snow covered surfaces using SAR images in Los Andes of Argentina and Chile

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**Abstract.** This work is part of the project: "Use of space technology for monitoring snow, glaciers and high mountain meadows in the central Andes of Argentina and Chile" framed in a program named “Opportunity Announcement (AO)”, carried out by CONAE and formed by SAOCOM 1A and SAOCOM 1B satellites. The rivers of the region under study, on the border between the Province of San Juan, Argentina and the IV Region of Coquimbo, Chile, of nivo-glacial regime, are the only source of water for human use, energy production, and native wildlife.

The snow-covered area (SCA) is an important parameter since it is used in snowmelt runoff models. The use of SAR images allows estimating the SCA in large areas of the Andes which are usually covered with clouds for the most part of the year. The procedure designed by Thomas Nagler and Helmut Rott (2000) using COSMO SkyMed was followed here. Initially, co-registration, calibration, reduction spekle and orthorectification procedures were performed. Then, maps of wet snow were generated using a threshold (TR) to separate snow-covered surface from the snow-free one. In this case TR = -2.5 dB.

The used algorithm applies change detection between two images with the same imaging geometry: one wet snow covered image, acquired during accumulation season (May to September) and one reference image without wet snow (February to April).

Since the area includes high mountains, up to 6,000 m, there is a significant loss of information. Therefore, it was very helpful to orthorectify the images as well as to incorporate the ascending and descending passes.

The comparison with snow maps from SPOT images shows good results in general.

SCA was determined at different height ranges and it was found that a high percentage of wet snow surfaces correspond to the range between 3001 and 4000 m.

**Keywords.** Snow Cover Area (SCA), Los Andes range, COSMO Skymed, change detection methods

## 1. Introduction

This work is part of the project: "Use of space technology for monitoring snow, glaciers and high mountain meadows in the central Andes of Argentina and Chile" framed in a program named “Opportunity Announcement (AO)”, carried out by CONAE and formed by SAOCOM 1A and SAOCOM 1B satellites.

The snow-covered area (SCA) was obtained using COSMO SkyMed. It has been shown in others study areas as in alpine areas that due to the large availability of CSK images, it was possible to analyze the snow detection capability of X-band images with respect to different parameters and key points such as: the choice of the reference images, the influence of land cover in different snow conditions, the influence of the threshold to distinguish snow and no-snow areas (Callegari,M. et al, 2012) [1]

The General Objective of this study is the incorporation of satellite technology (SAR Synthetic Aperture Radar images band c, x and l) to identify snow cover areas, aiming to its use by water authorities of Argentina and Chile. One specific objective is the determination of SCA (Snow Cover Area) using SAR images (COSMO Skymed and in the future SAOCOM images) in multi-temporal analysis. The other is to evaluate the potential of radar images to feed flow prediction models in rivers of nivo-glacial regime.

Expected Results are i) the implementation of a methodology for the digital processing of SAR images aiming to the identification and evaluation of snow cover areas at an operative level, ii) to divulge and transfer this technology in other mountainous areas, especially those which are covered with clouds the most part of the year, such as the southern regions of Argentina and Chile and iii) to incorporate SAR data into the flow prediction models used by the water authorities in the Andean regions

## 2. Methods

### *2.1 Zone of study*

The study area is located in the Andean areas in the provinces of San Juan (Argentina) and Coquimbo (Chile), latitude 29° and 32° 30’ south and longitude 69° 30’ y 70° 30’ west. It belongs to the fragile ecosystems of the Andean mountain areas with arid climates where precipitated snow melts and feeds the rivers of the region. This is the only source of water for human use, productive activities, energy as well as for native wildlife (Salinas de Salmuni, G.et al, 2008) [2].

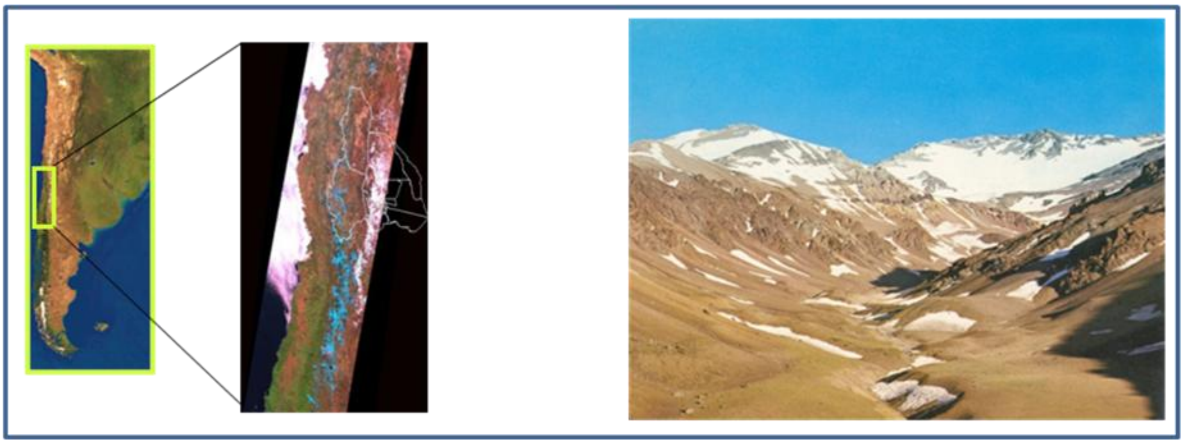


**Figure 1.** The study area located at the Andean zones of Argentina and Chile.

### *2.2 Materials*

The Images used were COSMO SkyMed, Strip Map HIMAGE. Two different sets of images were used: 1) Reference Image (master) obtained in February, between the end of summer and beginning of autumn. Most surfaces are free of snow or covered with dry snow. 2) Image acquired during the accumulation season (Slave) which can last up to five months, in July, from the end of autumn until springtime, Figure 2.

**Table 1.** COSMO SKYMED images used in the study.

| | Image 1 | Image 2 | Image 3 | Image 4 |
|---|---|---|---|---|
| Mission | CSK4 | CSK2 | CSK4 | CSK2 |
| Date | 03-Jul-12 | 06-feb-12 | 4-feb-12 | 09-jul-12 |
| Product type | DGM_B | DGM_B | DGM_B | DGM_B |
| Pass | Ascending | Ascending | Descending | Descending |
| Polarization | HH | HH | HH | HH |
| coordi- | 32°00'2 | 32°00'1 | 31°59'2 | 32°00'2 |

| | | | | |
|---|---|---|---|---|
| nates | 0" S | 0" S | 1" S | 5" S |
| | 70°15'4 6" W | 70°15'5 6" W | 70°15'4 1" W | 70°15'2 5" W |

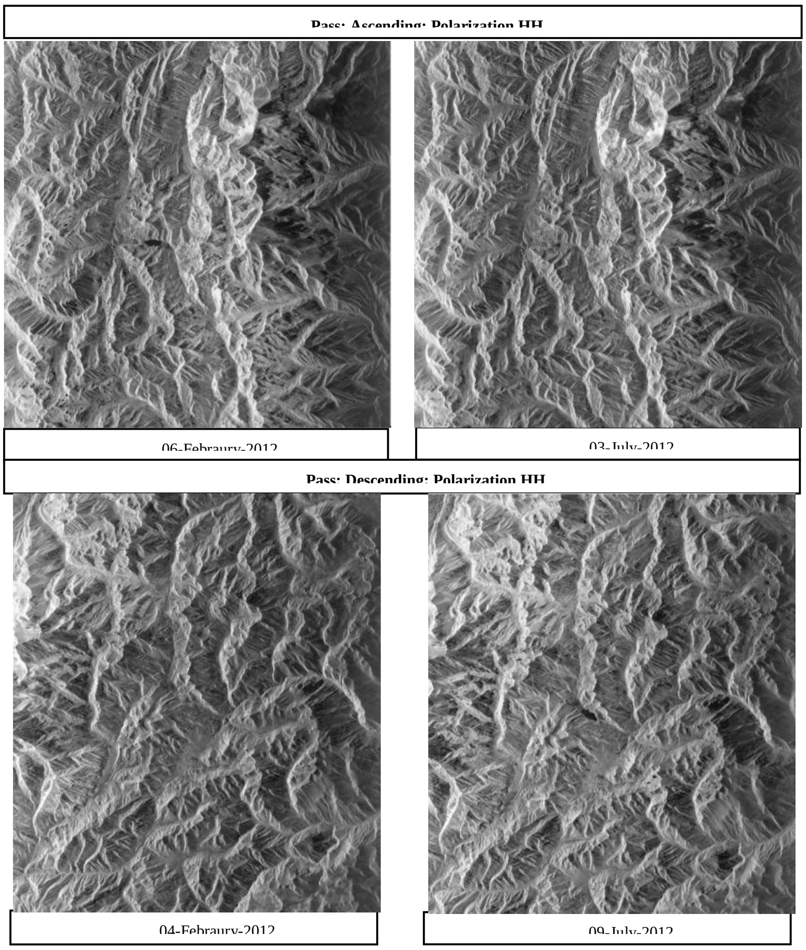



**Figure 2.** COSMO Skymed images used: on the left the references images obtained in February and on the right the slave images obtained in July.

In this study the Global Digital Elevation Model Version 2 (GDEM V2) is used, obtained with Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) images. The software was NEST DAT 4C, from European Space Agency (ESA).

## *2.3 Methods*

The methodology developed in this work consists in the production of binary maps of wet snow cover, through the processing of COSMO SKYMED data and their validation with SPOT data.

The SCA was obtained following the procedure designed by Nagler and Rott (2000) [3]. The processing of COSMO SKYMED images was performed in two main stages: The first included co-registration, calibration, speckle reduction and ortho-rectification (Figure 3), together with layover-shadow masks (Figure 4), both in ascending and descending modes, generating a ratio image of wet snow using a reference image (acquired during the period of no snow cover), Figure 5.

The second part consisted in the generation of binary maps of wet snow cover by using a threshold which discriminates between surfaces with and without snow cover, the snow binary mask.

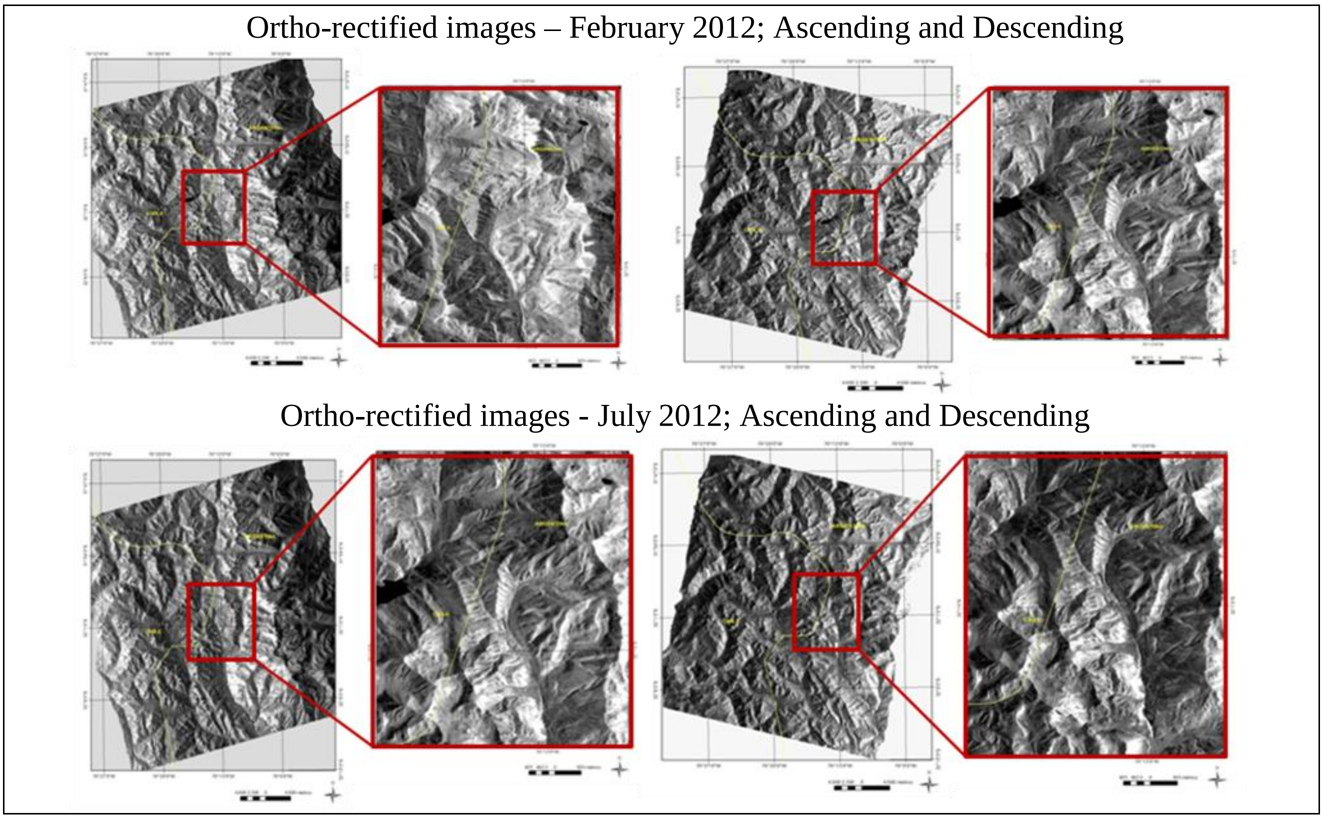



**Figure 3.** COSMO SKYMED images after the co-registration, calibration, speckle reduction and ortho-rectification, processing, both in ascending and descending modes.

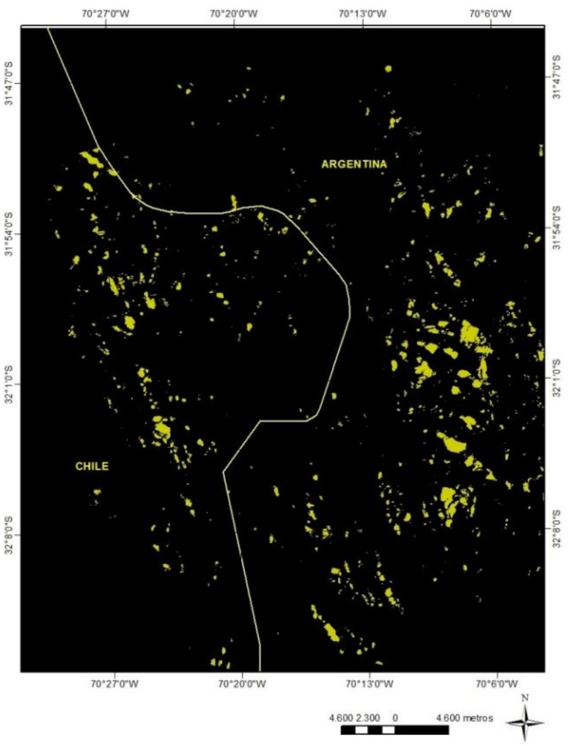



**Figure 4.** Layover – Shadow image, combination Ascending and Descending modes.

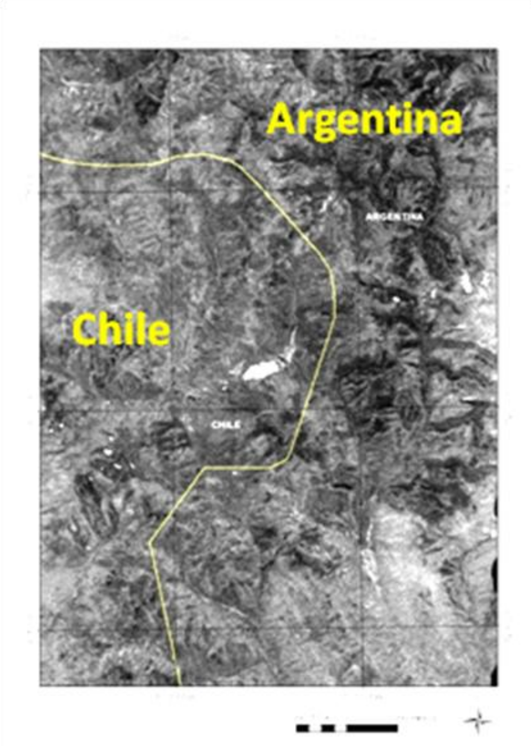



**Figure 5.** Image combination Asc-Desc, generated from the ratio Ascending image and the ratio Descending image.

### *2.4 Validation process*

For the validation of the SCA obtained with COSMO images, the snow map with SPOT image was used, generated through the NDSI (Normalized Difference Snow Index) method (Hall, D. et al, 1995) [4], (Salomon V. et al, 2005) [5].

The confusion matrix was generated using different Thershold ( 2 dB and 2.5dB respectively) and a comparison was made between SCAs obtained with SAR images in July, and the SCA SPOT image of the same date.

## 3. Results

### *3.1. Final mapping of wet snow*

Different thresholds were applied to the obtention of the wet snow binary mask. Figure 6 shows the final result is a wet snow map and a mask of lost data.

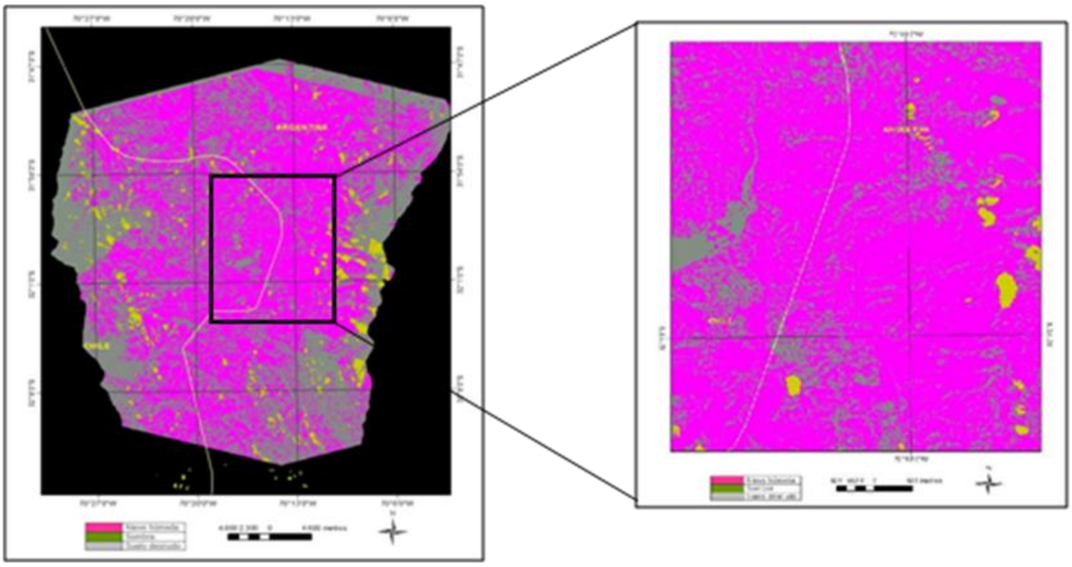


**Figure 6.** Final mapping of wet snow. Wet snow covers (magenta), layover – shadow zones (yellow) and snow free zones (grey).

### *3.2. Comparison between Descending and Ascending modes (separated and combined)*

**Table 2.** Descending Mode. Threshold – 2 db

| **Clas ses** | **Number of pixels** | **Area (km²)** | **Percentage (%)** |
|---|---|---|---|
| Wet snow | 3164963 | 601,93 | **33,64** |
| No snow | 6126177 | 1165,1 1 | **65,12** |
| shad ows | 116354 | 22,13 | **1,24** |
| | 9407494 | 1789,1 8 | **100,00** |

**Table 3.** Combination Ascending-Descending. Threshold – 2 db

| **Classes** | **Number of pixels** | **Area (km²)** | **Percentage (%)** |
|---|---|---|---|
| Wet Snow | 3164963 | 601,93 | **33,64** |
| No Snow | 6126177 | 1165,1 1 | **65,12** |
| Shadows | 116354 | 22,13 | **1,24** |
| | 9407494 | 1789,1 8 | **100,00** |

| Classes | Number of pixels | Area (km²) | Percentage (%) |
|---|---|---|---|
| Wet Snow | 4674320 | 888,99 | **58,262** |
| No Snow | 3090091 | 587,69 | **38,516** |
| Shadows | 258459 | 49,16 | **3,222** |
| | 8022870 | 1.525,84 | **100,000** |

*3.3. Snow cover at different altitudes*

The snow cover mask (Figure 6) was overlapped with the Digital Elevation Model. An altitude range segmentation was applied (Figure. 7). Then, the number of pixels assigned to each range was calculated, thus obtaining as a result the surface of wet snow cover, discriminated by altitude.

The results are shown in Table 4, and indicate that 35% of wet snow cover occurs within the range of 3001 to 4000 m altitude. The spatial distribution of wet snow diminishes over an altitude of 500 m. Those results are very similar of the obtained with optical data. (Argento et al 2012) [6]

**Table 4.** Wet snow cover at different altitudes

| Altitude (m) | total | Nªpixel | wet snow % | area km² |
|---|---|---|---|---|
| 1-1000 | 0 | 3924470 | 48,963 | 0,000 |
| 1001-2000 | 108 | 3924578 | 0,001 | 0,021 |
| 2001-3000 | 48979 | 3973557 | 0,611 | 9,315 |
| 3001-4000 | 2671415 | 6644972 | 33,329 | 508,066 |
| 4001-5000 | 1344684 | 7989656 | 16,777 | 255,740 |
| 5001-6000 | 24996 | 8014652 | 0,312 | 4,754 |
| 6001-7000 | 545 | 8015197 | 0,007 | 0,104 |
| total | | | | **778,000** |

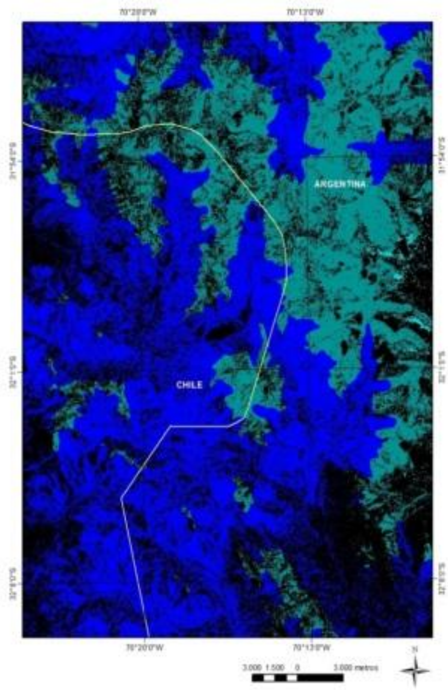



**Figure 7.** Image of surface of wet snow cover, discriminated by altitude, in blue surfaces over an altitude of 3,000 m .

*3.4. Snow Cover validation*

The snow map with SPOT image was generated using the NDSI data (reference samples) from a Image SPOT 10/07/12 very close to the date of COSMO Skymed image from 09/07/12. Tables 5 and 6 show the results of the confusion matrix using different thresholds (2 dB and 2.5dB respectively)

**Table 5.** Error matrix for july image, threshold -2dB

| classes | Snow cover | No snow cover | mix | total | Accuracy User% |
|---|---|---|---|---|---|
| Snow cover | 38 | 1 | 2 | 41 | 92.68 |
| No snow cover | 3 | 12 | 3 | 18 | 66.66 |
| mix | 10 | 2 | 10 | 22 | 45.45 |
| total | 51 | 15 | 15 | 81 | |
| Accuracy Producer | 74.50 | 80.00 | 66.66 | | |
| Total Accuracy | 38+12+10 = 60/81 = 74,04 | | | | |

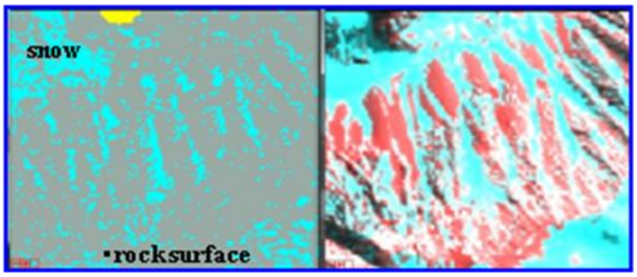
**Table 6.** Error matrix for july image, threshold -2.5dB

| classes | Snow cover | No snow cover | mix | total | Accuracy User % |
|---|---|---|---|---|---|
| Snow cover | 30 | 1 | 0 | 31 | 96.68 |
| No snow cover | 4 | 12 | 4 | 20 | 66.66 |
| mix | 13 | 1 | 9 | 23 | 39.13 |
| total | 47 | 15 | 13 | 74 | |
| Accuracy Producer | 68.82 | 80.00 | 69.23 | | |
| Total Accuracy | 30+12+9 = 51/74 = 68,91 | | | | |

Comparison between SCAs obtained with SAR images in July, and the SPOT image of the same date.

**Table 7.**

| **Snow Cover** | **TR (umbral)** | **Superficie %** | **TR (umbral)** | **Superficie %** |
|---|---|---|---|---|
| COSMO Skype | -2 dB | 40,85% | -2,5 dB | 35,30% |
| SPOT Image | 0,4 | 40,72% | 0,5 | 33,70% |




## 4. Conclusions

Best results are obtained from combined processing of images (ASC y DESC modes).
Use of (-2 dB) threshold brings more precise results than using a lower threshold (-2.5 dB)
The accumulation zone of the basin occurs above 3.000 meters over sea level.
The accuracy of snow cover evaluation was 90%, while the estimation of no snow cover gave much less values of accuracy, due to its heterogeneity “mixture of snow and rock outcrops”
The similitude of results obtained with optical images (SPOT) and radar images (COSMO) indicates that the adopted methodology is adequate and that the master image of February has been correctly chosen.

*Future Activities*

Multi-temporal studies with images dated in April, July and September.

Analysis of backscattering coefficient in various zones within the basin aiming to discriminate between wet and dry snow.

The installment of three meteorological stations field within the area under study operated by the Water authority in the province of San Juan (Argentina) in order to obtain better field data to be used in results validation.

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